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Abstract. We experimentally demonstrate transmission of cable television (CATV) radio frequency signals over a pointed indoor optical wireless link. The length of the optical link was 15 m. Collimators used at both the transmitter and the receiver sides required good alignment before sufficient optical power could be received. The system was placed at a height of 2 m, which is more than average human height, so human movements throughout the room did not obstruct the link. The optical wireless propagation path was almost lossless. The originality in this experimental demonstration is the transmission of full range of CATV signals compared to other works in this area. This experiment of radio over free-space optics showed that point-to-point indoor optical wireless links can be utilized as an alternative means for transmission of multimedia data. [DOI: 10.1117/1.OE.52.10.100503]

Subject terms: infrared laser; indoor optical wireless communications; cable television; radio over free space optics; line-of-sight link.

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1 Introduction

Indoor optical wireless links can be broadly categorized as line-of-sight (LOS) and non-LOS links.[1] LOS links may require some alignment based on the transmitter and the receiver designs, but they can provide higher bandwidth at lower power levels. Power levels are an important factor to consider when employing laser sources because of eye-safety issues. As the name implies, LOS links have limited mobility, and link blockage by human movement may become an issue. Nonetheless, LOS links are attractive for applications such as datacenters, transmission from fixed ceiling location to anywhere else in the room, e.g., in gaming systems, etc. Non-LOS links, on the other hand, are important for mobility considerations.

Experimental measurements for non-LOS links[2,3] or diffuse links, as they are termed in literature, have shown that non-LOS channels can support high data rates exceeding 2 Gbit/s and are limited by the receiver photodiode rise time and fall time. Techniques reported in Refs. 4 and 5 enable high data rates and mobility at the same time by employing quasi-diffuse links.

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LOS demonstrations using laser sources have mostly been done in terms of outdoor free space optical (FSO) links, where atmospheric conditions provide significantly more challenges than indoor conditions. Very high speeds in outdoor FSO links have been reported in Refs. 6–8. An interesting approach that makes use of limited mobility via diffused beam as well as high data rates achievable by LOS links is demonstrated in Ref. 9.

In this letter, we demonstrate an LOS indoor optical wireless link over a distance of 15 m carrying CATV transmission. Previous works in this area were related to the CATV uplink system.[10,11] CATV signals are RF signals, and hence, these systems are essentially radio-over-FSO systems. We also show that the propagation path is almost lossless and hence, it is very suitable for transmission of analog signals such as CATV RF signals as well as digital signals for data transmission.

2 Experimental Setup

The block diagram in Fig. 1 shows the basic setup. CATV transmission source is supplied by cable operators, which is transported by a coaxial cable to the laser transmitter. We used OTOT-1000C-08-FF28 from Olson Technology, Inc., California. This transmitter employs a direct modulation laser source emitting wavelength at ITU channel 28, i.e., 1554.94 nm. The laser is simply intensity modulated by the RF signal of CATV transmission. The transmitter has a bandwidth ranging from 48 MHz to 1 GHz, supporting full range of CATV analog and digital multichannel transmission. The output of the transmitter is coupled to a single-mode fiber (SMF) and is intended for fiber transport in the range of 0 to 10 km according to manufacturer specifications.

The SMF was coupled with a collimator that enabled free-space laser transmission. The receiver collimator was placed 15 m across the room. The collimators were placed at a height of 2 m so that human movement would not cause link blockage. The specifications of both the collimators are given in Table 1.

Figure 2 shows the transmitter and the receiver lens assembly.

Both the transmitter and the receiver collimators were placed on three-axis positioners. It was necessary to set up a good alignment between the transmitter and the receiver collimators before sufficient optical power could be received at the receiver end.

The receiver collimator focuses the radiant laser beam into an SMF, which goes to the receiver demodulation circuit. We used OTPN-400C from Olson Technology, Inc., California that employs a simple detector circuit (with a

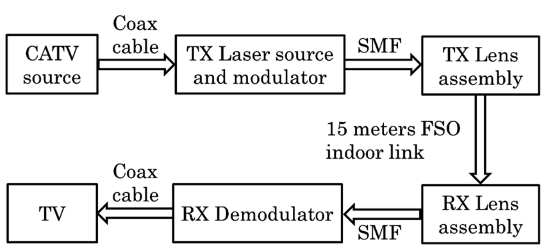

Fig. 1 Block diagram of demonstration of cable television (CATV) transmission over a 1550-nm link.

Table 1 Transmitter and receiver collimator specifications.

	Transmitter	Receiver
Collimated beam diameter	3.6 mm	7 mm
Divergence angle	0.032 deg	0.016 deg
Focal length of lens, f	18.75 mm	37.13 mm
Diameter of lens	5.5 mm	24 mm

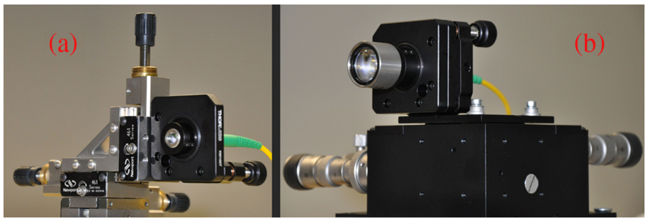

Fig. 2 (a) Transmitter collimator assembly and (b) receiver collimator assembly.

photo-detector having an active area diameter of 0.5 mm) and outputs the RF signal. According to manufacturer specifications, the input optical power level range required for the device to work is between −1 and −8 dBm.

The RF signal is carried by a coaxial cable and is fed directly to a TV. Figure 3 shows a sample screenshot from one of the channels playing on the TV.

Measurements were taken at various points of the system. It was observed that at the surface of the receiver lens, the beam diverged at such an extent that its diameter was more than the sensor diameter of the optical power meter. Hence, we had to use an extra focusing lens (with focal length $f =$ 200 mm and diameter 48.5 mm) to focus the beam onto the sensor of the optical power meter while measuring power. The optical loss of this focusing lens is measured at the transmitter side. Hence, we can compare the wireless optical path loss between the transmitter and the receiver lens. Measurement values are given in Table 2.

As is seen from Table 2, the received optical power after coupling is −4.57 dBm, which is enough to make the demodulation circuit work. Thus, we did not need an amplifier such as an erbium-doped fiber amplifier to amplify the received optical signal. With better coupling and better

Fig. 3 Sample screenshot from one of the channels playing on the TV.

Table 2 Measurements taken at various points of the system.

Point at which optical power was measured	Optical power	
At the output of TX laser source (including 3-m fiber optic patch cable)	8.02 dBm	
	Without extra focusing lens	With extra focusing lens
At the output of TX collimator lens	7.87 dBm	6.90 dBm
At the surface of RX collimator lens	N/A	6.87 dBm
After RX collimator lens but before SMF is coupled	6.58 dBm	Not needed
At the input of RX demodulator receiver node (including 3-m fiber optic patch cable)	−4.57 dBm	Not needed

alignment, it is expected that the received power after coupling will be >0 dBm.

There were 65 analog channels and 64 digital channels in the CATV transmission link. For the sake of visual comparison, the spectra of the whole RF bandwidth, an individual analog channel, and an individual digital channel on both the transmitter and the receiver sides are shown in Fig. 4.

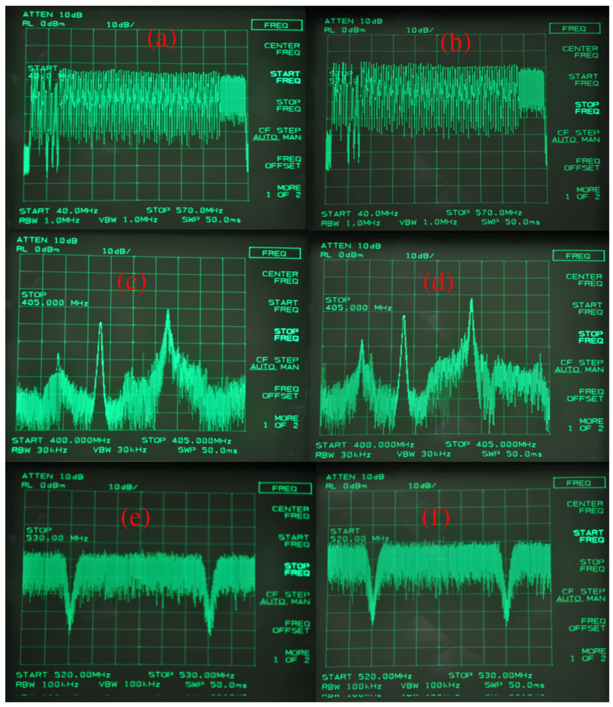

Fig. 4 (a) Complete spectrum of the CATV RF link from the transmitter side, (b) complete spectrum of the CATV RF link from the receiver side, (c) spectrum of an individual analog channel from the transmitter side, (d) spectrum of an individual analog channel from the receiver side, (e) spectrum of an individual digital channel from the transmitter side, and (f) spectrum of an individual digital channel from the receiver side.

The spectrum remains flat, without any distortion after the transmission through optical link.

The system was placed at a height of 2 m, above average human height. This allowed the link to remain completely independent of human movements throughout the room. Only blocking the link intentionally by hand would disrupt the link.

Also according to Table 2, the emitted optical power from TX lens was 7.87 dBm. According to laser safety standards,[12] it is well within the eye-safety limit.

Though this experiment focuses on the entertainment side by transmitting CATV signals over an optical link, it can also be easily used for very high data rate transmissions. This has an interesting application note in case of datacenters. Datacenters have racks of servers. Each of these racks communicates with each other via a top-of-the-rack (ToR) switch. The links between these switches are usually oversubscribed,[13] e.g., supposing that 30 machines are connected to a ToR switch with 1 Gbps links, and the ToR switch is connected to an aggregate switch (to connect with other ToR switches) with a 10 Gbps link, this link is said to be oversubscribed at a 1:3 ratio. Inserting a secondary link at this point that can carry 10 to 20 Gbps of data via an optical wireless channel can improve the performance of ToR switches, leading to a decreased time for completion of tasks for the datacenter.

3 Conclusions

Through this work, we emphasize the importance of indoor optical wireless links both at home and in other indoor environments. At home, a setup such as ours can be utilized for entertainment purposes. Utilizing high data rates, the same setup can be used in datacenters leading to advantages such as uncluttered space and faster operation. The optical propagation path is almost lossless, thus the system will not require amplifiers and will work with receivers that do not have very good sensitivities.

Acknowledgments

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References

1. J. M. Kahn and J. R. Barry, "Wireless infrared communications," *Proc. IEEE* **85**(2), 265–298 (1997).
2. H. Hashemi et al., "Indoor propagation measurements at infrared frequencies for wireless local area networks applications," *IEEE Trans. Veh. Technol.* **43**(3), 562–576 (1994).
3. J. Fadlullah and M. Kavehrad, "Indoor high-bandwidth optical wireless links for sensor networks," *J. Lightwave Technol.* **28**(21), 3086–3094 (2010).
4. S. Jivkova, B. A. Hristov, and M. Kavehrad, "Power-efficient multispot-diffuse multiple-input-multiple-output approach to broad-band optical wireless communications," *IEEE Trans. Veh. Technol.* **53**(3), 882–889 (2004).
5. G. Yun and M. Kavehrad, "Spot-diffusing and fly-eye receivers for indoor infrared wireless communications," in *Proc. IEEE Int. Conf. Selected Topics in Wireless Communications*, pp. 262–265 (1992).
6. K. Tsukamoto et al., "Development of radio on free space optics system for ubiquitous wireless," *PIERS Online* **4**(1), 96–100 (2008).
7. P.-L. Chen et al., "Demonstration of 16 channels 10 Gb/s WDM free space transmission over 2.16 km," in *Digest of the IEEE/LEOS Summer Topical Meetings*, pp. 235–236 (2008).
8. E. Ciaramella et al., "1.28-Tb/s (32 40 Gb/s) Free-space optical WDM transmission system," *IEEE Photonics Technol. Lett.* **21**(16), 1121–1123 (2009).
9. K. Wang et al., "4×12.5 Gb/s WDM optical wireless communication system for indoor applications," *J. Lightwave Technol.* **29**(13), 1988–1996 (2011).
10. Y. Tanaka, K. Tomoioka, and M. Takano, "Wireless CATV uplink system with subcarrier modulation using infrared communications for apartment houses," *IEICE Trans. Commun.* **84**(12), 3235–3242 (2001).
11. Y. Tanaka, "A study on optical wireless communication systems and their applications," Ph.D. Dissertation, Keio University (2002).
12. International Electrotechnical Commission (IEC), "Safety of Laser Products—Part 1: Equipment classification and requirements," International Electrotechnical Commission (IEC) Standard 60825-1 (2007).
13. D. Halperin et al., "Augmenting data center networks with multi-gigabit wireless links," in *Proc. ACM SIGCOMM Conf.*, pp. 38–49 (2011).